

# U.S. Coast Guard Research and Development Center

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## MODELING OF LEEWAY DRIFT



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<b>16. Abstract (MAXIMUM 200 WORDS)</b>  This document reviews the existing state of practice in the computation of leeway drift. Five documents were specified for review. One document was found to be unavailable. All four remaining documents used essentially the same governing equations for the body motion. These equations are well known and widely used. After definition of terms, the generalized analysis of the force balance of a drifting object in the open ocean is presented. Comparisons of the generalized presentation with two of the referenced papers are made to show the parallelism of approach. An idealized measurement program is defined to parallel the theoretical formulation. A set of sensitivity analyses to test the relative contribution of the various terms and parameters in the model analysis is presented. Recommendations for future work, both in the laboratory and the field, are presented.					
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## EXECUTIVE SUMMARY

This report was prepared for the USCG R&D Center as an overview of the current state of practice for modeling leeway drift as it applies to search and rescue (SAR) mission planning. The intent of this effort was to make an initial assessment of what would be required to develop a math model of leeway. Such a model could be used in combination with field experiments to provide accurate prediction of wind-driven search object motion for mission planners. It was expected that this approach to leeway prediction would be more economical and efficient than field experiments alone, resulting in the ability to provide leeway data on the many classes of search objects more economically. While the mathematical modeling approach may indeed provide some economies over a purely empirical approach, the report documents that math models will still need empirically-derived inputs to be accurate. The value of this study is in documenting what will need to be done in order to develop a reliable math model. The study is one piece of ongoing R&D Center efforts to better-define object movement due to leeway, and in turn feed new generation search planning tools with the objective of reducing size and search mission costs through better movement prediction.

This report is a companion for Allen and Plourde, 1998, "Review of Leeway Field Experiments and Implementation," and reviews four documents that model leeway dynamics. The four documents use essentially the same force balance solution to the drifting body problem. The four reports include two documents by Su (Su (1986) and Su et al. (1997)) which were prepared for the USCG R&D Center. Both of these documents contain a development of the theoretical background of the leeway dynamics problem and the equations governing the wind and water forces on a leeway object. Su et al. (1997) restates the theoretical presentation and includes laboratory results for air and water drag coefficients. Su's field experiments suffered from short duration and a lack of real time ocean current data collection. A third paper, Richardson (1997), that focuses on the leeway of ships under power, has limited application to the SAR problem. The fourth report, Hodgins and Mak (1995), develops force balance equations and includes an experimental program to obtain air and water drag coefficients for two specific life rafts. Hodgins and Mak addressed issues of model scaling effects and boundary layer effects.

In this presentation, the common approach to the development of the physics of the leeway problem is restated. Essential force terms acting on the leeway object are defined. The assumptions and simplifications used in the formulation of the leeway problem in physical terms are presented. The problem is restated with reference to the papers of Su (1986) and Hodgins and Mak (1995) to show the parallelism of their approaches.

The resistance of floating objects to changes in velocity, inertial force and added mass is presented and discussed for objects with a range of masses. For light

bodies the inertial force is shown to be small and the object therefore responds rapidly to changing environmental forcing. Eliminating the inertial force for low mass SAR type objects simplifies the force balance equation. The forces associated with wind, wave, and water drag are each addressed in separate sections. A method for the parameterization of drag coefficients for water and air is discussed. Building on the work of Su (1986) and Hodgins and Mak (1995) an expression for the calculation of the body velocity is derived.

The authors suggest an "ideal" measurement program based on a set of sensitivity studies to test the relative contribution of model terms and parameters. Each parameter for each of the individual terms in the force balance equation is presented, classified and discussed. Parameters are classified by a matrix of air, wave, and water measurements and by the method of measurement (wind tunnel, tow tank, field experiment). Specific approaches to the laboratory collection of data to calculate wave forces and equilibrium drift angle and forces are presented. The direct method now in use by the U.S. Coast Guard R&D Center to measure leeway, which utilizes instrumented drift objects, is confirmed as a viable approach compatible with modeling efforts. The collection of simultaneous, independent fixed-frame surface current measurements during field experiments is suggested in the report.

The present state of leeway modeling is well developed from a theoretical point of view. Forces due to the action of wind, currents, and waves are adequately described. The governing physical equations, however, contain characteristics of the drift object and environment that are best presented as parameters within the equations. These parameters are often not well quantified. Because of this lack of understanding of the parameters relating to drag, lift, and torque, it is often difficult to accurately predict the direction of leeway drift even when the distance of the drift is of the correct magnitude. The Coast Guard will benefit by adopting a parametric approach to the classification of wind and water drag coefficients. This will allow the adjustment of generalized leeway equations for specific objects to better predict their movement through the water. Also, the collection of field data in extreme cases of wind-, wave-, and current-only forcing would benefit sensitivity testing of model parameters. Classes of leeway objects should be grouped, and parameters governing their drift should be quantified by experiment. Data from these experiments can be used to validate a dynamical model of leeway, and the model can then be used to interpolate results for non-tested drift objects.

## CHAPTER 1

### INTRODUCTION

This report is an overview of the current state of practice for the modeling of leeway drift for application to search and rescue (SAR). The report has been developed under contract to the USCG Research & Development Center as a companion for the Allen, 1998, "Review of Leeway Field Experiments and Implementation," which focuses on the field implementation of measurements of leeway drift. The report reviews specific source documents specified in the statement of work. These primary sources are listed in Appendix A. While the presentation of each of the specified documents is different, all of the referenced documents use essentially the same force balance solution to the drifting body problem.

Chapter 1 is an introduction of leeway definition and measurement, and gives some essential terminology definitions. Chapter 2 gives a generalized analysis of the complete force balance for a drifting object in the open ocean. Underlying assumptions and simplifications are presented as part of the development. Comparison with the two major references for the project (Su, 1986 and Hodgins and Mak, 1995) are made to show the parallelism of each approach. Chapter 3 introduces and discusses an idealized experimental measurement program to parallel the theoretical formulation with instrumentation and sampling to test model algorithms. It also discusses an ideal set of sensitivity analyses which focus on the definition of the effect of specific model parameters on the modeling of the trajectory of the drifting body. Chapter 4 presents conclusions and Chapter 5 recommendations.

#### 1.1 Leeway Definition and Measurement

For the search planner using manual methods, the components of leeway include leeway speed and leeway angle. Leeway speed has been interpreted as the speed at which the wind pushes an object through the water, leeway angle as the angle from the downwind direction in which the object has moved. Leeway may also be expressed in terms of downwind and crosswind components. Leeway as defined by the National SAR Manual is *that movement of a craft through the water, caused by the wind acting on the exposed surface of the craft*. Further refinements of the definition have been proposed by Fitzgerald et al. (1993), specifying the measurement elevations for wind speed and wind-forced currents in water. A discussion of these measurements and the changes in them over time may be found in Allen, 1998. Earlier leeway drift experiments have relied on intermittent sampling of the drifting object position, wind forcing, and local currents. More recent leeway field experiments have used continuous real time sampling of position, wind, and leeway on the drifting object (Allen, 1997, 1996a,b, Fitzgerald, 1993, 1994).

In this presentation, the movement of a drifting body is defined as the sum of the movement of the water supporting the body plus the leeway, the body motion relative to its surrounding water (linking the experimental procedures with the SAR / modeling theoretical development.)

## CHAPTER 2

### CALCULATION FORCE BALANCE ON FREE FLOATING BODY

#### 2.1 Introduction and Assumptions

We restrict attention to floating bodies without any internal means of propulsion (e.g. propulsion system, engine/propellor). The floating body may be a ship, boat, life raft, or swimmer lying in the water. There is no real limitation to practical shapes of any particular sort except that we shall suppose the body to be hydrostatically stable (e.g., the body will not capsize). This will limit our analysis to cases in which the effects associated with vertical body oscillations and rotations are small. Our goal is to define the trajectory of the body. The trajectory of the drifting object can be calculated from equations:

$$dx/dt=u_b(x,y,t) , \quad dy/dt=v_b(x,y,t) , \quad (1)$$

or, in vector form:

$$dr/dt=u_b(x,y,t) \quad (1a)$$

where:  $x(t)$ ,  $y(t)$  are the positions of the body in a fixed rectangular coordinate system and  $u_b$ ,  $v_b$  are the orthogonal components of the velocity in the  $x$  and  $y$  directions, respectively. These can be replaced by  $r$ , the position vector and  $u$ , the vector velocity of the drifting object.

These equations are similar to the ones used by the major documents reviewed for the paper. Su (1986) sets up a similar coordinate system. In contrast to the approach taken here, Su includes the surge and sway motions in his formulation, and makes some limited use of yaw motions later in his presentation. Yaw moments on the drifting object due to wind, water, and waves, and yaw damping are described in the model development. No sensitivity analysis is conducted by Su on the skill of his formulation with and without yaw; a scaling for the yaw damping coefficient is introduced and tuned to produce a minimum in overall deviation. Hodgins and Mak (1995) exclude heave, roll and pitch motions from their formulations, and accept that yaw will be of relevance to non-symmetrical objects, but limit their model development for the life raft problem. They exclude yaw on the basis of the near-symmetry of the bodies under study. Hodgins and Mak also explicitly define the assumptions: 1) air and water flows are incompressible, 2) constant, uniform air and water densities, 3) deep-water linear wave theory, 4) negligible wave resistance on the life raft hull (i.e., negligible resistance force from hull-generated waves), and 5) the raft is considered rigid in the flow.

To find the trajectory of the floating body  $\mathbf{r}(t)$ , we need to know the initial position of the body  $\mathbf{r}(0)=\{x(0),y(0)\}$  and its velocity  $\mathbf{u}_b(x,y,t)$ , which changes in space and time. The focus of the development is to define the velocity of the body.

Vertical body oscillations and rotations (heave, pitch, roll, and yaw) have some influence on the average velocity (i.e. the velocity as measured in intervals of several minutes), but these influences are small and can be neglected. Additionally, even neglecting water and wind motion, the calculation of these oscillations and rotations is very complicated (Wehausen, 1971).

## 2.2 Force Balance

The velocity of the body,  $\mathbf{u}_b$ , can be found from Newton's second law:

$$M' \frac{d\mathbf{u}_b}{dt} = \mathbf{F}_a + \mathbf{F}_w + \mathbf{F}_c \quad (2)$$

where:

$\mathbf{F}_a$  = air force

$\mathbf{F}_w$  = wave force

$\mathbf{F}_c$  = water force

$M' \frac{d\mathbf{u}_b}{dt}$  = inertial force

$M'$  is total mass (Lamb, 1932.)

$$M' = m + km'$$

where:

$m$  is the body mass,

$km'$  is added mass,

$m'$  is the mass of fluid displaced by the floating body.

The added mass coefficient  $k$  depends on the body shape ( $k=1$  for cylinder,  $k=.5$  for a sphere,  $k=.2$  for ellipsoid with  $a/b=2$ ).

For a floating body (2) takes the form

$$(1+k) A_w L_w \rho_w \frac{d\mathbf{u}_b}{dt} = \mathbf{F}_a + \mathbf{F}_w + \mathbf{F}_c \quad (2a)$$

We now address the conditions under which the inertial force will contribute significantly to the force balance for the drifting object. For example, consider the case when  $\mathbf{F}_w$  is neglected and  $\mathbf{F}_a$  and  $\mathbf{F}_c$  have the same direction we obtain (see (4) and (6) below):

$$2(1+k) A_w L_w \rho_w du_b/dt = C_d \rho_a A_a U_a^2 - C_{cd} \rho_w A_w u_b^2 \quad (2b)$$

where:

$A_a$  and  $A_w$  are body areas above and below waterline, respectively.

$L_w = V_w / A_w$ ,  $V_w$  is the volume of fluid displaced by the floating body.

$\rho_a$   $\rho_w$  are the densities of air and water, respectively.

$U_a$  is the wind speed.

$C_d$  is the air drag coefficient for the body.

$C_{cd}$  is the water drop coefficient for the body.

The solution of this equation is

$$u_b = u_0 \tanh(t/T),$$

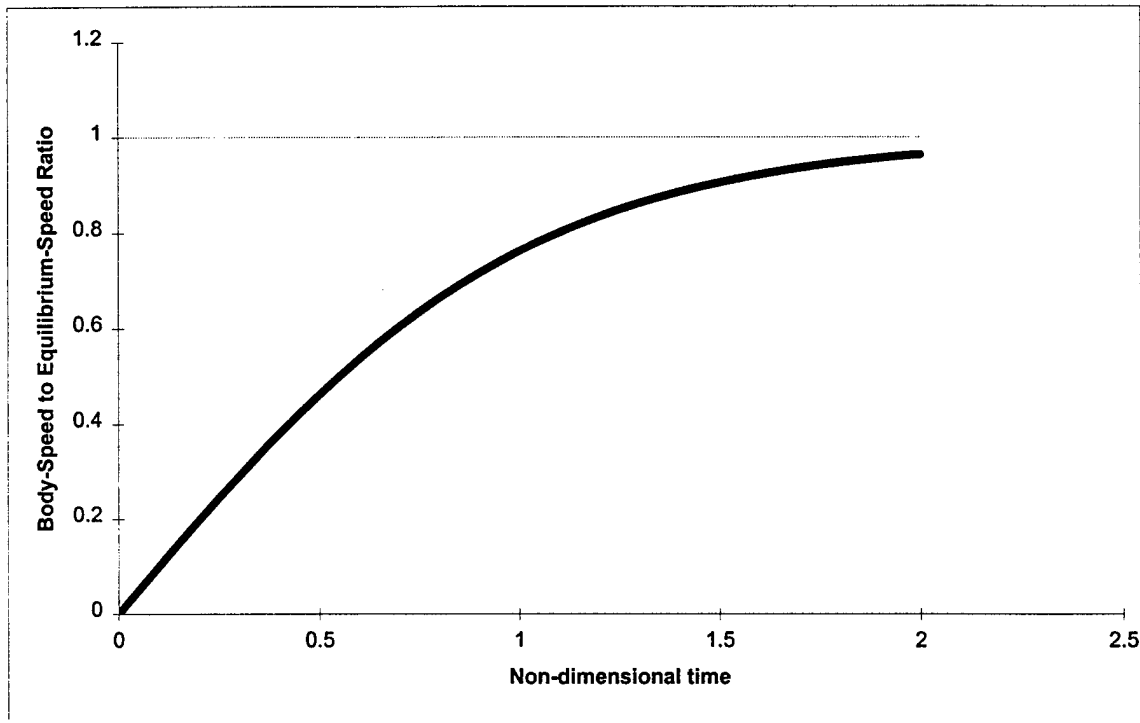


Figure 2-1: Body Speed to  $u_0$  ratio versus non-dimensional time.

where:

$$u_0 = U_a \left( (C_d / C_{cd}) (\rho_a / \rho_w) (A_a / A_w) \right)^{1/2}$$

and the non-dimensional time is given by:

$$T = 2(1+k) (L_w / U_a) / \left( (C_{cd} C_d) (\rho_a / \rho_w) (A_a / A_w) \right)^{1/2}$$

Considering that the density ratio for water to air ( $\rho_a/\rho_w$ ) is on the order of 840 and taking  $k=0.5$  we get

$$T \approx 100 (L_w/U_a) / ((C_{cd}C_d)(A_a/A_w))^{1/2}$$

Following, we substitute some values for one very massive object and for some typical SAR objects into the equation to find the predicted time for the body to reach equilibrium with steady wind forcing (as in Figure 2-1, right side).

For an iceberg with a 20 knot wind  $U_a \approx 10\text{m/s}$ ,  $L_w \approx 50\text{m}$ ,  $C_{cd}C_d \approx 1$ ,  $A_w/A_a \approx 8$  we have:  
 $T \approx 23\text{min.}$

For a floating swimmer with a 20 knot wind:  $U_a \approx 10\text{m/s}$ ,  $L_w \approx .5\text{m}$ ,  $C_{cd}C_d \approx 1$ ,  $A_w/A_a \approx 9$  we have:

$$T \approx 15\text{sec.}$$

For a vessel of 80m length, 2m draft, and average 4m superstructure:  $U_a \approx 10\text{m/s}$ ,  $L_w \approx 80\text{m}$ ,  $C_{cd}C_d \approx 1$ ,  $A_w/A_a \approx .3$  we have:  
 $T \approx 23\text{min.}$

For a swamped vessel of 5m length, 1.5m draft, and 0.2m "superstructure:"  $U_a \approx 10\text{m/s}$ ,  $L_w \approx 5\text{m}$ ,  $C_{cd}C_d \approx 1$ ,  $A_w/A_a \approx 7.5$  we have:  
 $T \approx 2.3\text{min.}$

For a supertanker of 300m length, 15m draft, and 5m "superstructure:"  $U_a \approx 10\text{m/s}$ ,  $L_w \approx 300\text{m}$ ,  $C_{cd}C_d \approx 1$ ,  $A_w/A_a \approx 3$  we have:  
 $T \approx 1.4\text{hr.}$

We see that for small bodies, the inertial term is important only for a very short time, and will therefore have a very small influence on the overall trajectory of the floating body. The environmental forcing (wind and current fields) are typically changing on a time scale measured in hours, rather than minutes. Thus, the inertial term will not substantially affect the steady state behavior of the floating body. The inertial term can be important for massive bodies which experience strong accelerations (e.g. an iceberg moving from an area of strong current to still water, or from still water to strong current). For the vessels and objects subject to SAR procedures we may safely neglect the inertial force.

Su (1986) includes a term for added mass in his model development, but does not identify this term's input to the solution through any sensitivity analysis. Hodgins and Mak also include an added mass term, but do not identify the contribution of this added mass term to the model predictions.

If we accept that the inertial (left hand side) term of Equation (2) can be ignored for the typical SAR object, we obtain:

$$\mathbf{F}_a + \mathbf{F}_w + \mathbf{F}_c = 0 \quad (3)$$

Our problem is to determine the body velocity, which we can obtain from Equation (3),

We consider only the average velocity on a two-dimensional plane, neglecting vertical oscillations, pitch, roll, and yaw. We also neglect the inertial term in the force balance equation.

We will now break our problem into two parts: a) find the body velocity from Equation (3), b) knowing body velocities, calculate the body trajectories from Equation (1). Since the floating body under equilibrium conditions simply follows the water mass supporting it, we will consider the problem first for the case of weak wind, then for strong wind conditions.

### 2.3 Weak Wind Condition

When the wind speed has the same order of magnitude as the current speed, or less, its influence can be neglected, and the body velocity is almost the same as the current velocity (no leeway). In this case, we can substitute the current velocity for the body velocity on the right hand side of Equation (1) to get

$$dx/dt = u_c(x,y,t), \quad dy/dt = v_c(x,y,t) \quad (1b)$$

The determination of the temporal and spatial changing current field  $u_c(x,y,t)$  may be from numerous sources: tidal atlases, hydrodynamic models, local observations. With the increasing availability of fixed platforms and buoys positioned in our coastal water, local observations of currents are increasingly available. In the case of relatively stationary current patterns, a climatological mean current field may be adequate. Note that relatively smooth current fields may generate complicated trajectories. These trajectories may diverge strongly, due to only small changes of initial position. (Odulo and Reed, 1990)

In the weak wind condition we have a one-step procedure, because we set the body velocity equal to the known current velocity at the body. Under a strong wind condition, the difficult part is to find the body velocity and trajectory with a given wind velocity field.

## 2.4 Strong Wind Condition

In the strong wind condition, when the wind speed is much larger than the current and body speeds, all three terms in Equation (3) must be taken into account. In the three subsections below we treat each of the force equation elements separately: the wind force, the wave force, and the water force.

### 2.4.1 Wind Drag Force

Friction and pressure forces exerted by the wind on the upper part of the floating body result in the wind force  $F_a$ ; which has a downwind component (drag) and a cross-wind component (side force or lift). The drag component is always positive. The side force or lift component can be positive or negative. Thus in Figure 2-2,  $F_a$  is the wind force which is the sum of  $F_d$ , the drag force, and  $F_s$ , the side force, with  $U_a$  being the wind velocity.  $F_d$  is always in the direction of  $U_a$ .  $F_s$  has a direction normal to the wind direction, either to the right or left.

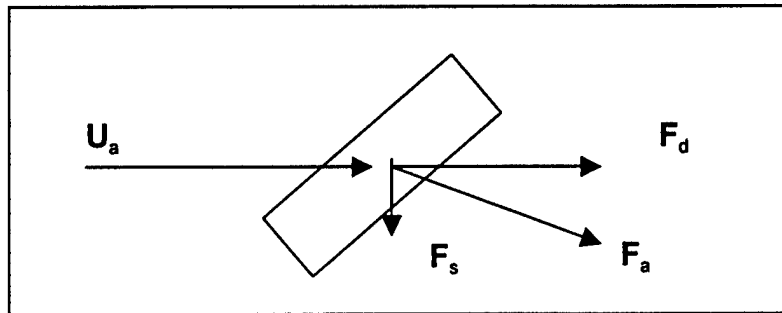


Figure 2-2. Force diagram for wind drag force.

The lift depends on the wind speed, body geometry, and strongly on the angle between the long axis of the floating body and the wind direction. If we can calculate the side force, we can include it in Equation (3) to find the body velocity. For now, we will approximate  $F_a$  by  $F_d$ , ignoring  $F_s$ .

The magnitude of the wind drag force is defined by

$$F_d = \frac{1}{2} C_d \rho_a A_a U_a^2 \quad (4)$$

where:  $F_d$  is the magnitude of the drag force,  
 $C_d$  is the air drag coefficient for the particular body shape,  
 $\rho_a$  is the density of air, and  
 $A_a$  is the projected frontal area of the floating body above the water's surface.

Drag coefficients for many body shapes have been empirically established, and their values widely published (see e.g. Hoerner, 1965.). Su (1986) references Owens and Palo (1982) for testing for large ships with values from 0.4 to 0.8 for superstructure drag values, and 0.15 for rafts. Hodgins and Mak (1995) obtained experimental values for  $C_d$  for two specific life rafts ranging from 0.22 to 1.14 over a range of Reynolds numbers ( $8 \times 10^4$  to  $9 \times 10^5$ ).

It is best to have an empirically derived drag coefficient for the particular body of interest. If not available, we must use a drag coefficient for a similar body shape (see Appendix C). It is worthwhile to note that a drag coefficient for a fully submerged body and floating body can differ significantly. The drag coefficient is a function of body shape, alignment in the flow, and Reynolds number. There are analytical expressions for drag coefficients of simple geometric shapes (sphere, disk, objects of revolution) and work has been done on some standard ship configurations. Beyond this small suite of shapes, additional wind tunnel experimentation is required.

The formulation for the magnitude of the lateral or side force,  $F_s$ , is the same as (4), except that the value of  $C_{dl}$  for the lateral force must be found independently. This lateral drag coefficient will be highly dependent on the angle with which the wind acts upon the floating body, and is in general difficult to obtain. Hodgins and Mak (1995) obtain lateral  $C_{dl}$  values for two life rafts ranging from 0 to 0.47 over a range of Reynolds numbers ( $8 \times 10^4$  to  $9 \times 10^5$ ).

In addition to the shape and orientation of the body, drag coefficients depend also on the Reynolds number:  $Re = UL/\nu$ , where  $L$  is a characteristic dimension of the body and  $\nu$  is the air kinematic viscosity. Usually drag coefficients are estimated under uniform air flow conditions. Hodgins and Mak (1995) show examples of a complete and well-conducted air tunnel test to compute the drag coefficient for two life rafts.

## 2.4.2 Wave Force

The theoretical development for computation of the wave force on the floating body is very complicated (e.g. Mei, 1992, Chapter 7). We can use the estimation that the magnitude of the wave force is:

$$F_w = \frac{1}{2} C_{iw} g \rho_w L_t A^2 \quad (5)$$

where:  $A$  is wave amplitude,  
 $C_{iw}$  is the incident wave reflection coefficient,  
 $g$  is gravitational acceleration,  
 $\rho_w$  is the density of water,  
 $L_t$  is the body length scale.

The direction of  $F_w$  is the direction of the wave group velocity,  $C_g$ , which often differs from the local wind direction.

Wave spectra can be calculated through empirical formulas (e.g., Coastal Engineering Research Center, 1984) which depend on wind speed, duration, and fetch. The computation for one set of conditions (wind speed, fetch, water depth) yields a wave amplitude and the direction of the wave group velocity  $C_g$  in terms of the wind.

Equation (5) gives the wave force due to the reflection of waves from the floating body and the impulse on the floating body from breaking waves. If the body reflects all the energy of incident waves then  $C_{iw}=1$  (Mei, 1992, p365). Generally, the coefficient  $C_{iw}$  in (5) must be found from experiments, similar to the coastal structures case.

Let us compare  $F_d$  and  $F_w$ , the wind drag force and the wave force:

$$F_w / F_d = (C_{iw} / C_d) (\rho_w / \rho_a) (gA / U_a^2) (L_t A / A_a)$$

It is clear that in this equation the amplitude of waves  $A$  reflected from the body and breaking on the body must be less than body height. Choosing

$$A = .5 \text{ m}, L_t A / A_a = .2, U_a = 10 \text{ m/s}, \rho_w / \rho_a = 840$$

we obtain:

$$F_w / F_d = 8.4 (C_{iw} / C_d)$$

Assuming  $C_{iw} / C_d$  is on the order of 1, we find that wave force can dominate under fully arisen sea conditions, and therefore the wave force must be included in our calculation.

The random nature of ocean waves makes it difficult to use the formulas for  $F_w$  presented above. Herbich, 1991 (pp.46-49) contains one technique which converts an ocean wave profile into a water particle velocity profile through a Fourier transform using linear wave theory. Knowing the velocity profile, the acceleration profile is computed, and wave forces are then determined from a formulation much used in the computation of wave forces on fixed structures, the Morison formula.

### 2.4.3 Water Drag Force

The water force is similar to the air drag force. We introduce the velocity of the body relative to the surrounding water:  $U_b'$ , Figure 2-3.

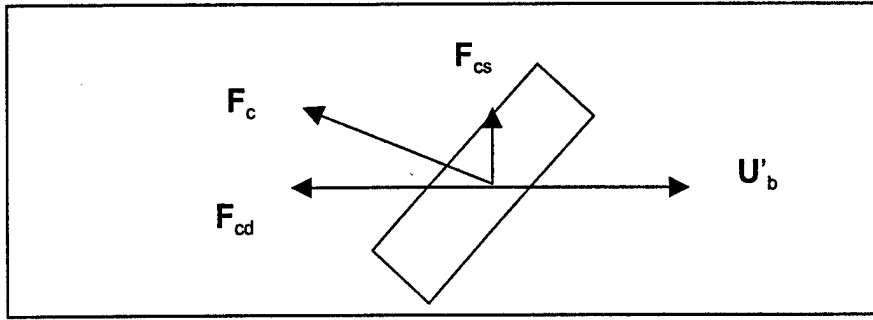


Figure 2-3. Force diagram for water drag force balance.

where:  $U'_b$  = body velocity relative to water (leeway)  
 $F_c$  = water force  
 $F_{cd}$  = water drag force (opposite direction of body velocity)  
 $F_{cs}$  = water lift force (normal to direction of body velocity)

For now, we will neglect the water lift force, using the same reasoning as for neglecting the air side force, above.

The magnitude of the water drag force is

$$F_{cd} = \frac{1}{2} C_{cd} \rho_w A_w U_b'^2 \quad (6)$$

where  $\rho_w$  is water density

$C_{cd}$  is an empirical drag coefficient, and

$A_w$  is the projected area of the floating body under the water.

There is an analogous formulation to Equation (6) for the side or lift force due to water, which contains  $C_{cs}$  for the side drag coefficient.

The shape of the wetted area of a floating body will, in general, be different from the shape and area of the body exposed to air. The Reynolds numbers for water and for air will also be different. Therefore  $C_{cd}$  and  $C_d$  will be different.

## 2.5 Calculation of Body Velocity

Substituting (4), (5) and (6) in Equation (3) we have the equation:

$$C_{iw} g \rho_w L_t A^2 C_g / |C_g| + C_d \rho_a A_a U_a' |U_a'| = C_{cd} \rho_w A_w U_b' |U_b'| \quad (7)$$

The left side of this equation is fully determined by the wind. So one can easily find  $U_b'(x,y,t) = \{u_b'(x,y,t), v_b'(x,y,t)\}$  in terms of a given wind record from this equation. The first (wave) term in (7) will not be obtainable under most conditions. Also note that although the first term represents wind-driven waves, these waves may have been generated far from the location of the floating body and propagated there, or the waves may have been generated within the same locale by an earlier wind event. Both of these factors add to the complexity of estimating the wave term in (7).

Having found  $u_b'$  and  $v_b'$  we can find the body velocity relative to the fixed system coordinates by using:

$$u_b = u_b' + u_c, \quad v_b = v_b' + v_c \quad (8)$$

Where  $u_c$  ( $u_c, v_c$ ) is the water velocity, which includes basic current (tidal current, streams) and upper mixed layer current due to wind (caused by wind stress, wave Stokes drift (which is negligibly small) and wave orbital velocity (which we neglect)).

Now, substituting (8) into (1) we can calculate the body trajectory. This means we can compute the body position in the fixed coordinate system at any time.

## CHAPTER 3

### IDEAL EXPERIMENTAL MEASUREMENT, SENSITIVITY STUDY PROGRAM

#### 3.1 Experimental Measurements

The conduct and analysis of experimental programs, both in the field and in wave tank or wind tunnel facilities, is expensive. Laboratory studies can measure forces directly to compute drag coefficients. Field studies follow the trajectory of drift objects and measure the external forcing (wind and wave) characteristics.

In the field experiment, we need to measure the location and attitude of the floating body and estimate each of the terms in Equation (3). In the laboratory experiment we must measure the force terms in Equation (3) under controlled conditions so that we can compute the drag coefficients.

$$\mathbf{F}_a + \mathbf{F}_w + \mathbf{F}_c = 0 \quad (3)$$

$\mathbf{F}_a$  is the air force on the body,  
 $\mathbf{F}_w$  is the wave force on the body, and  
 $\mathbf{F}_c$  is the water drag on the body.

For the air force term, we must measure

- wind speed,
- wind direction,
- $\mathbf{F}_d$  to compute  $C_d$  for the exposed area of the floating body,
- $\mathbf{F}_s$  to compute  $C_{dl}$  or drag coefficient for the lift force on the floating body,  
Note:  $\mathbf{F}_a = \mathbf{F}_d + \mathbf{F}_s$  Figure (2-2),
- the angle of attack of wind on the long axis of the floating body (Relative Wind Direction),
- ❖ exposed area of the floating body above water.

For the wave force term, we must measure (from the reference frame of the floating object):

- wave amplitude,
- wave direction,
- $\mathbf{F}_w$  to compute  $C_{iw}$  the incident wave reflection coefficient (Equation (5)),
- ❖ floating body length scale.

For the water drag force term, we must measure (from the reference frame of the floating object):

- speed of body relative to water,
- direction of body motion relative to water,

- $F_{cd}$  to compute  $C_{cd}$  for the wetted area of the floating body (Equation (6)),
  - $F_{cs}$  to compute  $C_{cs}$  or drag coefficient for the water lift force on the floating body,
  - the angle of attack of current on the long axis of the floating body, (Relative Current Direction)
  - ❖ exposed area of the floating body below water.
- note: terms marked with this symbol are freely changing in the field and are controlled inputs in laboratory experiments,
- note: terms marked with this symbol are measured in the laboratory; derived coefficients can be tested in the field,
  - ❖ note: terms marked with this symbol involve measurements of object dimensions.

From the data collection perspective the measurements will be grouped:

Table 3-1. Laboratory and Field Measurement Groupings.

	Wind Tunnel	Wave Flume Tow Tank	Field Experiment
air	$F_d, U'_a$ $F_s$ Exposed area		$U'_a$ angle of attack of wind
wave		$F_w, A$ Length scale	$A$ (wave direction)
water		$F_{cd}, U'_b$ $F_{cs}$	$U'_b$ , angle of attack of current

The wind tunnel laboratory experiments yield estimates for  $C_d$  and  $C_{dl}$ .

The wave tank laboratory experiments yield estimates for  $C_{iw}$ .

The tow tank laboratory experiments yield estimates for  $C_{cd}$  and  $C_{cs}$ .

The field experiments measure wind speed and direction, water speed and direction, wave amplitude, and drifting object locations.

A schematic wave flume configuration for the measurement of  $F_w$  is pictured below in Figure 3-1:

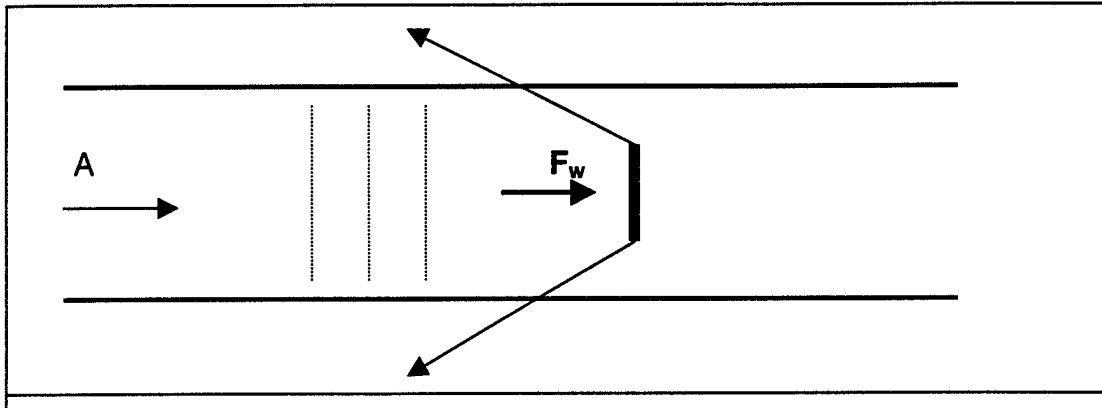


Figure 3-1. Schematic for calculation of wave force.

The incident wave amplitude is measured, as is the characteristic length of the fixed body. Dynamometers on the restraining members will measure the force necessary to hold the body in place.

Figure 3-2 shows a schematic for the computation of the equilibrium drift configuration for a drifting object.

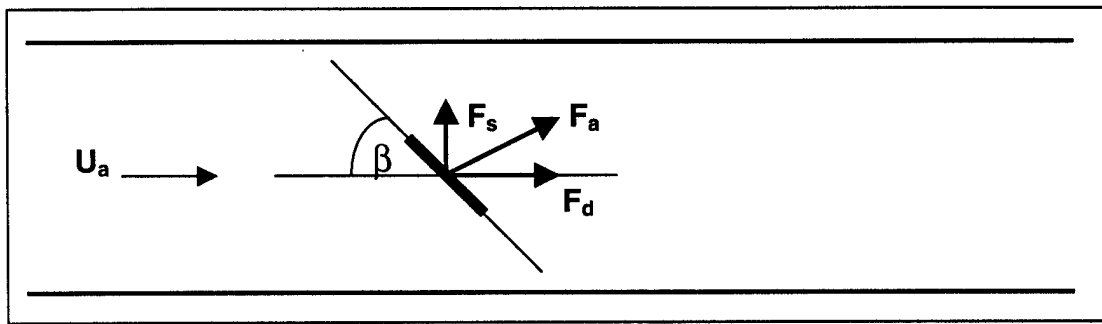


Figure 3-2. Schematic of laboratory experiment to compute equilibrium drift angle  $\beta$  and forces.

A first experiment would allow the body to drift freely, to calculate the equilibrium drift angle  $\beta$ . A second series of experiments would fix the body in the wind field, and measure the wind forces on the body with dynamometers.

Each of the forces is calculated on the floating body itself and will be determined relative to the floating body. This requires that the field experiment instrumentation

and measurement of the observed wind speed and direction, and current speed and direction, should take place at the floating object.

### **3.2 Sensitivity Analyses**

Once all data have been collected, archived, and made available for analysis, the path of each floating object can be computed according to Equations (1, 7, 8), time-step by time-step. Sensitivity analyses for the inclusion of individual terms (e.g. wave force term) and in the formulation for drag coefficients can then be performed in an iterative fashion on this consistent data set. The intent of these sensitivity analyses is to establish the relative contribution of each of the forcing terms to the successive displacements of the body. These analyses are useful in that they point up the relative contribution of each of the forcing functions for a particular body of experimental data.

## **CHAPTER 4**

### **CONCLUSIONS**

This report presents an overview of the state of practice for the modeling of leeway drift for application to search and rescue (SAR). We have reviewed the models of leeway dynamics presented in four papers and reports. All investigators used a similar approach to the prediction of the movement of a drifting object on the water surface, based on a balance of forcing from wind, waves and water drag.

Richardson's paper (1997) on leeway error in historical ship drift current velocity shows a parallel approach to the steady state force balance between air and water drags, but is not relevant because it is focused on ships under power.

Su's two reports have the same development, which is complete, but contains a great deal of detail about the orientation of the floating body. Although the theoretical formulation is good, the experimental design and results in Su's reports are of limited use.

Hodgins and Mak (1995) is a well-written study, and is especially good in the wind and tow tank experimentation. The field trial in this study suffers from the lack of an independent current measurement for the surface flow field. Some sensitivity analysis is presented for Stokes drift, whitecap drift, water side (lift) force. Coriolis force and wave force are shown for two hindcasts.

The focus of any leeway model is to define the velocity of the floating body. Vertical oscillations and rotations are judged to be small. Compared to the time scales of the environmental factors (wind, waves, and currents) affecting leeway, the inertial time scale of the SAR drift bodies will be small and not substantially affect their steady state behavior.

Leeway resulting from wind speeds of the same order of magnitude as that of the ocean current speed will be small. At these wind speeds, leeway can therefore be neglected and the body velocity can be considered equal to the current velocity.

Wave forces dominate only under conditions when the sea state is fully developed.

The theoretical development of the leeway problem presented in the two most relevant documents (Hodgins and Mak (1995), and Su (1986)) is sufficient to satisfy the needs of leeway modeling for SAR. The force balance and velocity computation for the floating body require some slight adjustments to reconcile the differences between specific approaches. The chief shortcoming in the computation of leeway is not in the theoretical development but in the formulation and quantification of the parameters used in the theoretical development. Parameters based on analyses of the wind drag force, wave force, and water drag force balances are needed to solve

the problems associated with drift angle and wave effects. Each of the forces on the floating body must be calculated separately and verified by field experiments that collect wind speed and direction, current speed and direction, wave height, and body position. Sensitivity analyses are required to establish the relative contribution of each of the forcing terms to the successive displacements of the drifting body.

Current techniques used to directly measure leeway are judged to be adequate and should be applied to a wide range of SAR target types.

## CHAPTER 5

### RECOMMENDATIONS

Laboratory experiments will yield estimates of drag coefficients. Field experiments will yield data on the dependence of drifting bodies with the associated wind and wave forcing. Combining the laboratory-derived coefficients and theoretical force balance with the field collected trajectories and forcing data, we can apply the theory developed above in iterative fashion to test various formulations for the computation of generalized leeway prediction for search and rescue mission planning. Larsson (1990) contributes the following matrix of data, experimentation, and calculation in what he calls a velocity prediction program "structure."

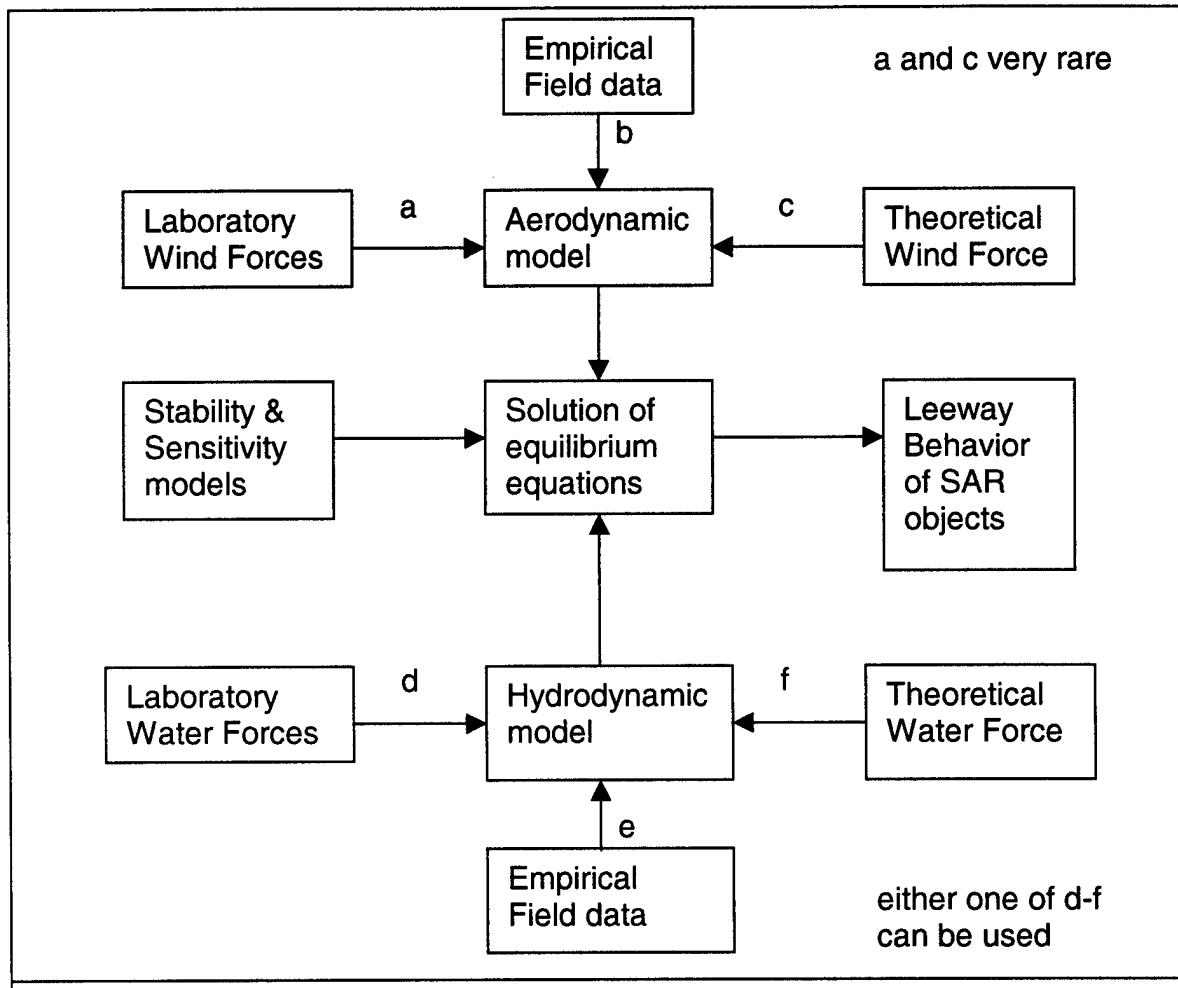


Figure 5-1. Velocity Prediction Program Structure (after Larsson, 1990 with changes)

## 5.1 Laboratory Experiments

Wind tunnel measurements of  $C_d$ ,  $C_{dl}$  have been derived from experiment for some simple geometric shapes and recently for specific lifeboats. The cost and time to compute these values for all types of classifications of search objects would be prohibitive. A formulation which parameterizes the ratio of the above water and below water areas of search objects may lead to a method to classify search objects' drag coefficients. Sailing performance calculations (Milgram, 1998; Larsson, 1990) have addressed similar physics for optimizing sailboat speed. A study of these analyses may yield useful insights about the characterization of drag and lift forces on vessels, especially sailing vessels, whose shapes are designed to promote forward movement of the hull from predominantly transverse force balances.

One suggested approach may be for the generic calculation of free drift angle.

Compute the broadside and fore-and-aft above and below water areas for the object (below water areas hatched):

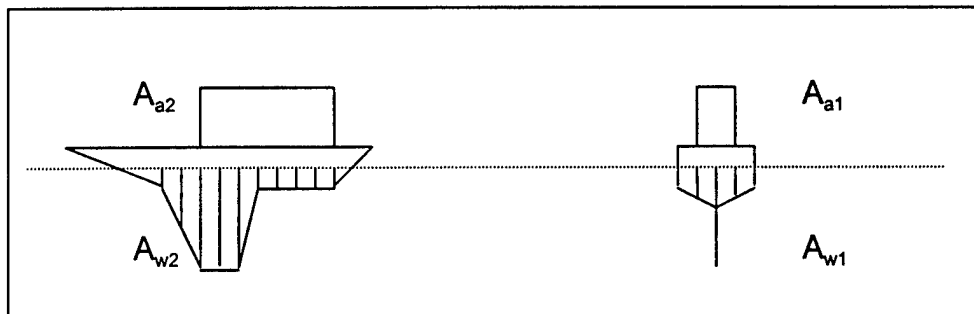


Figure 5-2. Broadside and fore-and-aft air and water exposed ratios.

Define the ratios of fore-and-aft to broadside areas for this characteristic hull shape:

$$\alpha_a = A_{a1} / A_{a2} \quad \text{above water area ratio}$$

$$\alpha_w = A_{w1} / A_{w2} \quad \text{below water area ratio}$$

Holding the above water area ratio constant (e.g. 1.0), vary the below water area ratio and achieve a set of drift angles under similar wind forcing conditions. Change the above water area ratio and repeat. The expectation is that some smoothly changing function may arise:

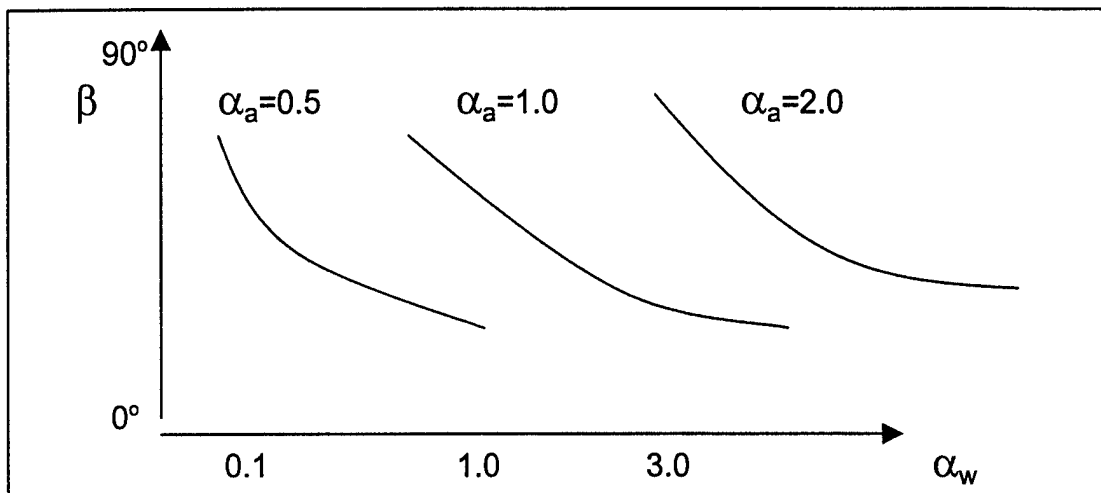


Figure 5-3 Dependence of body orientation on body shape. (Curves are hypothetical.)

## 5.2 Field Experiments

The experimental design of the field experiment program should seek to sample a range of environmental conditions which covers the range expected for SAR applications. This, of course, is a difficult task.

It would be useful for the experimental design to include extreme cases of the three forcing mechanisms: (a) a wind force dominated area (e.g. drifting body released in a short fetch area in an enclosed estuary), (b) a wave forced area, and (c) current-dominated area. The experimentalist and data analyst may then satisfy themselves about each of the forcing mechanisms and their contribution separately.

The additional collection of surface current data within the area of the drifting body is necessary to determine the wind and externally forced movement of the water body supporting the drifting object. It will be useful to set up a fixed reference near-surface current meter and make multiple replicates of the tested drifting object through this known water velocity field. This may be accomplished by repeatedly releasing the drifting object upwind of the fixed current meter. The current meter should be moored as close to the draft of the drifting object as practical.

The formalization of a structure such as Larsson's Velocity Prediction Program would be useful in the clarification of the goals and interactions of the various laboratory, field, and numerical modeling tasks needed to improve the computation of leeway drift. The development of such a structure could also enhance the interactions of the experimentalist, theorist, and numerical analyst.

### **5.3 Relevance to USCG Leeway Studies**

Allen and Plourde (1998) propose a leeway taxonomy that describes over 1600 leeway drift objects. However, based on experiments documented over the years, leeway values are recommended for only 64. This is only four percent of the proposed leeway drift objects. It is clearly not practical to determine leeway values by conducting field experiments on the remaining 96 percent.

Therefore it is recommended that field experiments be used to study “keystone” leeway drift objects. Model parameters should then be measured on these same targets, and a model run. The model results can then be compared against direct measurement field tests in order to validate the model. Once the model is validated, it can be used to interpolate between “keystone” targets within the taxonomy of targets. This manner of combining modeling and field efforts will provide the Coast Guard with more accurate movement prediction for numerous search targets rather than just a select few.

## REFERENCES

The following references, in addition to the primary reviewed documents, were used in the preparation of this report.

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Allen, A.A. and R.B. Fitzgerald, 1997. The Leeway of a Open Boat and Three Life Rafts in Heavy Weather, U.S. Coast Guard, U.S. Coast Guard Report No. CG-D-03-98.

Allen, A.A., 1996a. The Leeway of Cuban Refugee Rafts and a Commercial Fishing Vessel, U.S. Coast Guard Report No. CG-D-21-96.

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Fitzgerald, R.B., D.J. Finlayson, J.F. Cross, and A. Allen, 1993. Drift of Common Search and Rescue Objects – Phase II, Contract report prepared for Transportation Development Centre, Transport Canada, Montreal, TP# 11673E.

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Herbich, John B. and C.L. Bretschneider, 1991. Handbook of Coastal and Ocean Engineering, Vol. 2: Offshore Structures, Marine Foundations and Sediment Processes, and Modeling. Gulf Publishing Company, Houston, TX. 1991.

Hodgins, D.O. and R.Y. Mak, 1995. "Leeway Dynamic Study Phase I Development and Verification of a Mathematical Drift Model for Four-person Liferrafts." Prepared for Transportation Development Centre, Transport Canada Report #TP 12309E.

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Su, T.C., Q. Robe and D.J. Finlayson, 1997. On Predicting the Person-in-the-Water (PIW) Drift for Search and Rescue.

Su, T.C., 1986, On Predicting the Boat's Drift for Search and Rescue, U.S. Department of Transportation, Report No. DOT/OST/P-34/87/059.

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## APPENDIX A

### LISTING OF THE PRIMARY DOCUMENTS REVIEWED FOR STUDY

Following is a list of documents required for review in this study, with an overview of the primary findings of the authors from the review.

*Summary comments on all papers described below:*

*All (Su, Hodgins, Richardson) use simple governing equations for body motion. Su is the most fully developed and Richardson the least (because of the problem addressed). These equations are well known and widely used.*

*For most problems a simpler set of equations will probably suffice: a balance between water and wind drag forces. In any case some sensitivity studies addressing the full force balance and equations of motion is in order. This sensitivity study would sort out which of the forcing terms is important in a predictive sense and which are not.*

*Su (Person in Water study) and Hodgins (life raft study) lab experiments are interesting, reasonably well done, and provide important information for the definition of drag coefficients for the objects tested.*

*Most of the field data, while interesting, is of limited use, since it generally doesn't do a good job of estimating/determining the current field. There is also a tendency to believe that anything that a near surface drogue measures is a "current" and not related to "winds." This is generally a bad assumption, as wind-induced flows can readily impact near surface circulation.*

Central Tactics and Trial Organization (CTTO). 1974. "Life Raft Drift Rates." CTTO/10756/44/LRMO, Canada.

*This document appears to be not available, even from the agency listed as authoring the document.*

Hodgins, D.O. and R.Y. Mak, 1995. "Leeway Dynamic Study Phase I Development and Verification of a Mathematical Drift Model for Four-person Liferrafts." Prepared for Transportation Development Centre, Transport Canada Report #TP 12309E.

*The study is well written, and demonstrates a well-executed program to obtain  $C_d$  values for air and water drag for two specific life rafts. Hodgins and Mak (1995) employs a conventional modeling approach. The wind and tow tank experimentation was well designed and implemented, generating a useful data set*

*of air and water drag coefficients for the tested life rafts with adequate care taken to address issues of model scaling effects and boundary layer effects of the wind tunnel. Between repetition testing results are small, indicating a high degree of confidence in the results.*

*The attempt to verify the model predictions through hindcast is impossible, since there were no independent measurements of current speed during the field trials used. An attempt to use observed drift to infer the currents seems flawed and circular.*

*The study does not complete a full sensitivity analysis to infer which of the terms of the force balance in the formulation contribute to the solution. Some comparison of the velocity terms computed for Stokes drift and Whitecap drift, water side (lift) force, Coriolis force, and wave force are shown for two hindcasts.*

Richardson, P.L., 1997. Drifting in the Wind: Leeway Errors in Shipdrift Data. Deep-Sea Research I, Vol. 44, No. 11.

*A well written and interesting paper, but not particularly relevant to the problem at hand, since the data used in the study are all derived from ships under power. It is interesting to note that the solution for the governing equations is a simple steady state force balance between air and water drags, similar to the result of the Hodgins and Mak (1995) report.*

Su, T.C., 1986, "On Predicting the Boat's Drift for Search and Rescue," U.S. Department of Transportation, Report No. DOT/OST/P-34/87/059.

*Very good development of the theoretical background of the problem: perhaps a little complicated, but comprehensive.*

*Most of the experimental programs reported were not successful. Chief problems are with experimental goal and design. The field experiments suffered from a lack of good measurements of currents.*

*Model data comparisons lack sensitivity studies, and all are of very short duration (on the order of hours).*

Su, T.C., Q. Robe and D.J. Finlayson, 1997. "On Predicting the Person-in-the-Water (PIW) Drift for Search and Rescue."

*The theory section is a repeat (almost word for word) of the 1986 report.*

*The lab results to obtain air/water drag coefficients are useful and interesting. Drift factors derived seem reasonable.*

*Field experiments are of limited use, once again because there is inadequate collection of current data.*

*All experiments are of very short duration (a few hours).*

*There is no real verification of the model. In spite of claims in the text, the model predictive performance is not very good. For two hour simulations, errors in final position amount to twenty percent relative to path length for simple cases with no complicated flows or nearby boundaries.*

*No sensitivity study performed with models, hence we don't know what terms of the formulation are important and what terms are not. Also we don't understand what limits the quality of the prediction.*

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## APPENDIX B

### RESULTS OF A COMPUTERIZED SEARCH REFERENCES ON THE FOLLOWING KEY WORDS AND AUTHOR CITATIONS

#### Key words:

- leeway
- life raft drift
- search and rescue
- ship drift
- shipdrift
- person-in-water drift
- person in water drift
- drift model
- mathematical drift model

#### Author citations:

In addition to the primary references for this study:

Chapline, W.E. 1960 "Estimating the drift of distressed small craft,"  
Coast Guard Alumni Association Bulletin, U.S. Coast Guard Academy, New  
London, CT Vol. No. 2. March-April, 1960, pp39-42.

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## NISC DISC REPORT

MARINE, OCEANOGRAPHIC & FRESHWATER RES. 1985 - Mar. 1997

\*\*\*\*\*

DATABASE: IOSDL/POL

TITLE: The determination of slippage of drifters and the leeway of search and rescue targets using InterOcean S4 EMCM.

AUTHOR: ALLEN, A.A.

SOURCE: pp.151-156 in, Proceedings of the IEEE Fifth Working Conference on Current Measurement, February 7-9, 1995, St. Petersburg, Florida. [ed.S.P.Anderson et al] . Taunton, MA: William S. Sullwold Publishing. 270pp. & appendices.

KEY TERMS: drifters; woce; labrador current; atlnwlab; marine technology

LIB. LOCATION: WOR B OCEAN [Apparatus & Meth] , BID B551.46.018 AND

**ALLEN, A.A.** The determination of slippage of drifters and the leeway of search and rescue targets using InterOcean S4 EMCM. pp.151-156 in, Proceedings of the IEEE Fifth Working Conference on Current Measurement, February 7-9, 1995, St. Petersburg, Florida. [ed.S.P.Anderson et al] . Taunton, MA: William S. Sullwold Publishing. 270pp. & appendices.

DATABASE: ASFA - Part 2

TITLE: Spring 1985 leeway experiment.

AUTHOR: Nash , L.; Willcox, J.

INST. AUTHOR: Coast Guard Research and Development Cent., Groton, CT (USA)

SOURCE: REP. U.S. COAST GUARD RES. DEV, 123 pp; 1991

ABSTRACT: The U.S. Coast Guard R and DC and Florida Atlantic University (FAU) conducted an experiment off the east coast of Florida during March and April 1985 in order to determine the leeway of various craft common in Search and Rescue (SAR) situations. Leeway, defined as the response of a survivor craft to the effect of wind alone, is an important component of the total drift calculation for a survivor craft. Other components are the sea current, tidal current, and wind-driven current. Leeway data will be utilized by search planners to predict the movement of various search targets. The search targets evaluated were three types of 4-man life rafts, one 6-man life raft, and three types of small boats (less than 21 feet in length). This report presents results of the R and DC's statistical analysis. Results of FAU's use of the data to calibrate and test a numerical model are presented separately, DOT/OST/P-34/87/058, August 1986. Leeway was calculated as the difference between the test craft's velocity and the average current of the upper three feet of the water column. The oceanic surface current at the test craft was determined from an array of drifters surrounding the test craft. The drifters and small craft were tracked by a Microwave Tracking System (MTS). The wind was measured onboard

the small craft at a height of six feet above the ocean surface. The apparent wind relative to the current at the raft was used in the analysis. (DBO)

KEY TERMS: ship design; search and rescue; lifeboats; life saving equipment; drogues; performance assessment

MAJOR TOPIC: Support Services, Techniques, and Equipment: Search and salvage [2390]; Technology and engineering

PUB. TYPE: Report

DOCUMENT LANG.: English

ABSTRACT LANG.: English

NUMBERS: CGR/DC-01/ 88. USCG-D-12-92

DATABASE: ASFA - Part 2

TITLE: Summer 1983 leeway drift experiment.

AUTHOR: **Nash, L.**; Willcox, J.

INST. AUTHOR: Coast Guard Research and Development Cent., Groton, CT (USA)

SOURCE: NTIS Order No.: AD-A163 568/9/GAR. USCG-D-35-85.; REP. U.S. COAST GUARD RES. DEV, 70 pp; 1985

NOTES: NTIS Order No.: AD-A163 568/9/GAR. USCG-D-35-85.

ABSTRACT: A new method of determining leeway was tested using three life rafts. The method was successful in differentiating the leeway of the light ballasted raft from the more heavily ballasted rafts. The leeway speed of the lightly ballasted raft was comparable to results in previous studies. The leeway speeds for the more heavily ballasted rafts were substantially less than those in a previous study. The leeway direction of the lightly ballasted raft was dependent on the raft's orientation to the wind with the two ballast bags acting as a keel. The more heavily ballasted rafts drifted directly downwind.

KEY TERMS: remote sensing; lifeboats; search and rescue; wind-driven currents; ship drift

MAJOR TOPIC: Support Services, Techniques, and Equipment: Search and salvage [2390]; Technology and engineering

ENVIRONMENT: Marine

PUB. TYPE: Report

DOCUMENT LANG.: English

ABSTRACT LANG.: English

REPORT NUMBER: CGR/DC-10/85

DATABASE: ASFA - Part 2

TITLE: Statistical models for the optimal estimation of oceanic fields.

AUTHOR: **Sun, L.C.**; Allen, A.A.; Billing, C.B.

INST. AUTHOR: Coast Guard, Washington, DC (USA). Off. of Research and Development

SOURCE: NTIS Order No.: AD-A211 786/9/GAR. RDC-10/87.; REP. U.S. COAST GUARD RES. DEV, 127 pp; 1989

NOTES: NTIS Order No.: AD-A211 786/9/GAR. RDC-10/87.

ABSTRACT: An investigation into the drift and leeway of survivors and survivor crafts is described, as part of the improvement of probability of detection in search and rescue. Part of this effort uses freely drifting buoys that transmit their positions to a shore/ship-based receiver to provide an estimate of the surface current field. The data sets are in the form of drift tracks from each drifter. To analyze the irregular spaced drifter tracks, objective analysis techniques were applied to produce optimal estimations of surface current fields on a regularly spaced grid. Transformation of a data set onto a regularly spaced grid allows use of many other standard computer analysis programs. A computer program using this technique was previously successfully applied to large oceanographic data sets of many drifter tracks. The objective analysis program was converted for use on Hewlett Packard microcomputers and applied to a much more limited data set from 6 drifters, the results being that objective analysis can effectively work with small data sets. A few well placed buoys provide better information than many poorly placed buoys. Therefore use of remotely sensed data will aid in determination of the optimal placement of buoys.

KEY TERMS: search and rescue; tracking; statistical analysis; computer programmes; drifting data buoys; ocean currents

MAJOR TOPIC: Support Services, Techniques, and Equipment: Search and salvage [2390]; Technology and engineering

ENVIRONMENT: Marine

PUB. TYPE: Report

DOCUMENT LANG.: English

ABSTRACT LANG.: English

REPORT NUMBER: USCG-D-10-89

DATABASE: COMPOSITE RECORD <sup>3</sup> ASFA - Part 2 <sup>3</sup> IOSDL/POL

TITLE: Leeway drift computations for search and rescue.

AUTHOR: **Park, Kwang-Soon**; Kang, See-Whan; Kang, Sin-Young

AUTH. ADDRESS: Ocean Environ. Eng. Lab., KORDI, Seoul, Rep. Korea

SOURCE: OCEAN RES. KOREA; vol. 10, no. 2, pp. 69-72; 1988

ABSTRACT: Prediction methods of the leeway drift for the research and rescue mission at open waters are introduced. A simple model to predict the drift position of each type of target is developed for operational use using formula introduced by CASP (Computer Aided Search Planning). In this model, the search area is determined by quadrilateral connected by 4 datums which are calculated for a given type of drift target when marine environmental factors such as wind and current are given. This program can be used operationally using the information provided by the real-time monitoring and marine forecasting system established by KORDI.

KEY TERMS: ship drift; position fixing; tracking; methodology; computer programmes; ships; monitoring systems; CASP [Computer Aided Search Planning]; wind; marine transportation; search strategies; search and rescue; safety; current <sup>3</sup> physical oceanography; wind driven currents

MAJOR TOPIC: Support Services, Techniques, and Equipment: Ocean operations [2388]; Technology and engineering  
ENVIRONMENT: Marine  
PUB. TYPE: Journal Article  
DOCUMENT LANG.: Korean  
ABSTRACT LANG.: English; Korean  
LIB. LOCATION: WOR SP, BID SP

DATABASE: COMPOSITE RECORD <sup>3</sup> ASFA - Part 2 <sup>3</sup> IOSDL/POL  
TITLE: Using GPS-equipped drift buoys for search and rescue operations.  
AUTHOR: **LEGER, G.T.**  
SOURCE: GPS World, 3 [10] , 36-38, 40-41.; 1994  
KEY TERMS: drifting data buoys; drifters; positioning systems; search and rescue; satellite telemetry; marine technology  
LIB. LOCATION: WOR SP, BID SP  
DATABASE: IOSDL/POL

TITLE: Predicting the drift of person-in-water for search and rescue.  
INST. AUTHOR: Florida Atlantic Univ., Boca Raton (USA). Cent. for Applied Stochastics Research  
SOURCE: NTIS Order No: AD-A249 613/1/GAR., 2 pp; 1992  
NOTES: NTIS Order No: AD-A249 613/1/GAR.  
KEY TERMS: search and rescue; drift; prediction; current meandering  
ABSTRACT: This report focused on three topics of interest: (1) Establishing the wind drag coefficient and current drag coefficient of Person-In-Water model through water channel test; (2) Investigation of accumulating effect of upstream disturbance on flow in the region of flow stagnation; and (3) Preliminary field test plans to verify the predicted floating body drift.  
MAJOR TOPIC: Support Services, Techniques, and Equipment: Search and salvage [2390]; Technology and engineering  
ENVIRONMENT: Marine  
PUB. TYPE: Report  
DOCUMENT LANG.: English  
ABSTRACT LANG.: English  
DATABASE: ASFA - Part 2

TITLE: Predicting the person-in-water drift for search and rescue.  
AUTHOR: **Su, T.**  
INST. AUTHOR: Florida Atlantic Univ., Boca Raton (USA). Cent. for Applied Stochastics Research  
SOURCE: 83 pp; 1990  
KEY TERMS: search and rescue; drift; offshore operations; current meandering  
ABSTRACT: Search and rescue of persons in distress on the high seas requires the capability to accurately predict the position of the survivors. The current approaches on drift prediction are based on an empirical correlation between wind speed and

person motion from limited field data. There is also no drift data available for persons wearing survival suits. Consequently, there is not sufficient data for accurate prediction and thus has complicated the search and rescue operation. A study is being undertaken at Florida Atlantic University in which the essential effects of environmental forces and person-in-water characteristics will be properly accounted for. The study is intended to provide a theoretical framework and a better understanding of the dynamics of drift, and will thus lead to a reliable model of drift prediction and improved efficiency in search and rescue missions. The study consists of the following components: the development of a mathematical model for the drift prediction problem, laboratory studies of drift forces and field experiments to calibrate the mathematical models and to verify the model prediction.

MAJOR TOPIC: Support Services, Techniques, and Equipment: Search and salvage [2390]; Technology and engineering

ENVIRONMENT: Marine

PUB. TYPE: Report

DOCUMENT LANG.: English

ABSTRACT LANG.: English

DATABASE: ASFA - Part 2

TITLE: On a Burmese fishing raft drifted to Madras.

AUTHOR: **Srinivasarengan, S.**; Vivekanandan, E.; Girijavallabhan, K.G.; Sarvesan, R.; Jayasankaran, L.

AUTH. ADDRESS: Madras Res. Cent., CMFRI, Madras, India

SOURCE: MAR. FISH. INF. SERV. TECH. EXT. SER., NO. 85, pp. 12-13; 1988

AVAIL.: Rec'd in 1989.

KEY TERMS: fishing vessels; fishermen; ISW, India, Tamil Nadu, Madras; floods; search and rescue; ship drift; rafts

ABSTRACT: On 6-12-1987, a fishing raft with three crew members was brought to Madras by local fishermen. The raft was from Piyapong Chonkaa, Burma. On 21-11-'87 the raft was anchored in River Iravati. Due to sudden floods in the river, the anchor got lifted and the raft drifted to the sea with three fishermen. The vessel drifted with the current in south-westerly direction for 16 days in the sea and was rescued by the local fishermen near Pulicat on 6-12-1987. There was no net in the raft at the time of rescue.

DOCUMENT LANG.: English

DATABASE: OCEANIC ABSTRACTS

TITLE: Real-time applied oceanography at the Navy's global center.

AUTHOR: **Clancy, R.M.**

AUTH. ADDRESS: Data Integration Dep., Fleet Numer. Oceanogr. Cent., Monterey, CA 93943, USA

SOURCE: Special issue: Applied oceanography.; Marine Technology Society journal. Washington DC; vol. 21, no. 4, pp. 33-46; 1987

NOTES: Special issue: Applied oceanography.

KEY TERMS: military oceanography; polar oceanography; dynamical oceanography; models; research programmes; marine technology; Fleet Numerical Oceanography Center; USN <sup>3</sup> physical oceanography; united states of america - research

ABSTRACT: Fleet Numerical Oceanography Center, currently runs many real-time ocean model systems operationally. Thermal structure models are used to provide input to sonar performance models. Circulation models, which account for the large scale wind driven currents, are used to predict the drift of objects in support of search and rescue applications. Wave models, based on a spectral formulation and "first-generation" physics, are used to predict the evolution and extent of dangerous sea conditions. Finally, ice models are used to predict various sea-ice parameters in support of the Navy's arctic operations.

GEO. AREA: usa, california, monterey

MAJOR TOPIC: Institutes and organizations [2102]

ENVIRONMENT: Marine

PUB. TYPE: Journal Article

DOCUMENT LANG.: English

ABSTRACT LANG.: English

LIB. LOCATION: WOR SP, BID SP

DATABASE: COMPOSITE RECORD <sup>3</sup> ASFA - Part 2 <sup>3</sup> IOSDL/POL

TITLE: Mathematical modeling of craft drift in an ocean environment.

AUTHOR: **Kang, S.Y.**

INST. AUTHOR: Florida Atlantic Univ., Boca Raton (USA)

SOURCE: Diss. Ph.D.: Order No.: FAD DA87 13258.; DISS. ABST. INT. PT. B - SCI. & ENG; vol. 48, no. 3, 173 pp; 1987

NOTES: Diss. Ph.D.: Order No.: FAD DA87 13258.

KEY TERMS: boats; fluid dynamics; oceanic province; yawing; surging; mathematical models

ABSTRACT: A mathematical model, which accounts for the essential effects of environmental loads and vehicle characteristics from a fluid dynamics point of view, is developed to forecast the position of a craft drifting on the sea surface. The study is intended to provide a better understanding of the dynamics of drift and thus to provide a reliable model of drift prediction for use in future search and rescue mission.

MAJOR TOPIC: Vessels, Underwater Vehicles and Buoys: Surface vehicles [2301]; Technology and engineering

ENVIRONMENT: Marine

PUB. TYPE: Book Monograph

DOCUMENT LANG.: English

ABSTRACT LANG.: English

DATABASE: ASFA - Part 2

**Hastenrath, S.;** Greischar, L. The monsoonal current regimes of the tropical Indian Ocean: Observed surface flow fields and their geostrophic and wind-driven

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## **Appendix C** Compilation of tables and figures relevant to the computation of wind and current drag coefficients.

### Drag coefficient

The drag and lift coefficients,  $C_d$  and  $C_L$ , depend on a body shape, the angle between body axis and flow, and Reynolds number (see Figures below from Schlichting (1960), Newman (1977), Hoerner (1965) Lampietti and Snyder (1965)). It is impossible to determine  $C_d$  and  $C_L$  theoretically and experimental methods must be used. The drag coefficient for spheres depends solely on one parameter, the Reynolds number, and is shown in Fig. 1.5. Fig. 1.4 represents the drag coefficient of circular cylinders as a function of the Reynolds number.

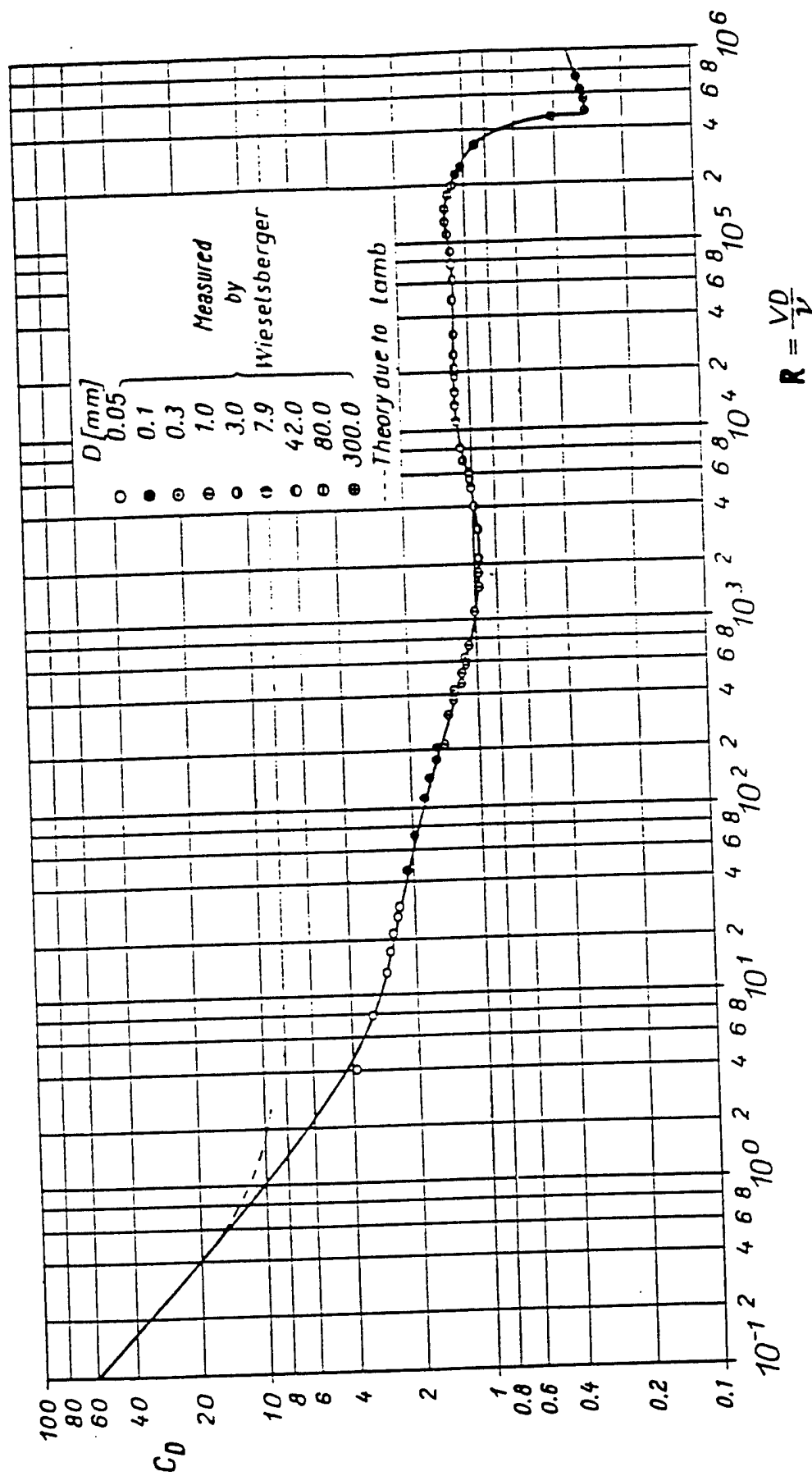


Fig. 1.4. Drag coefficient for circular cylinders as a function of the Reynolds number

Schlichting (1960)

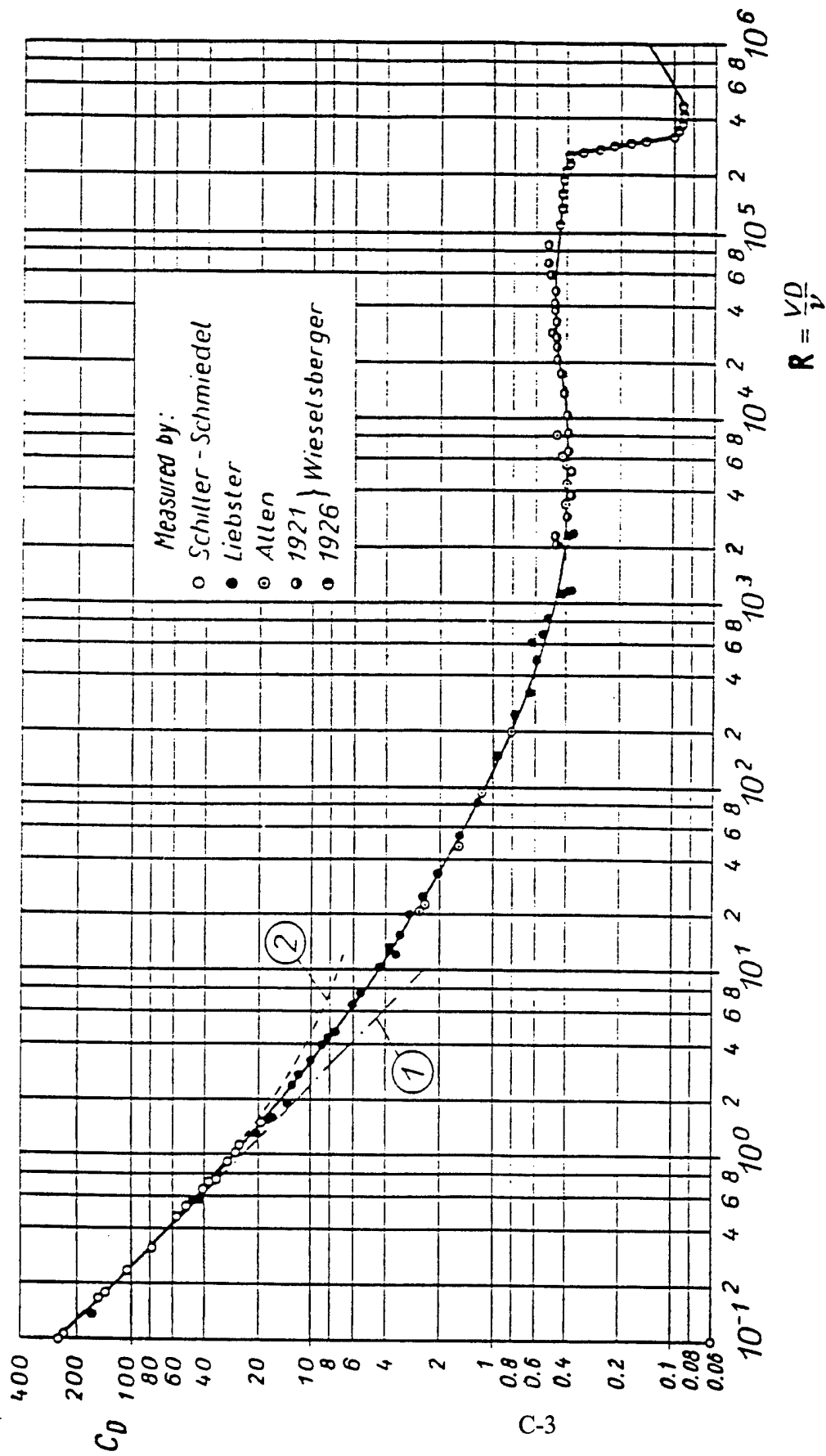
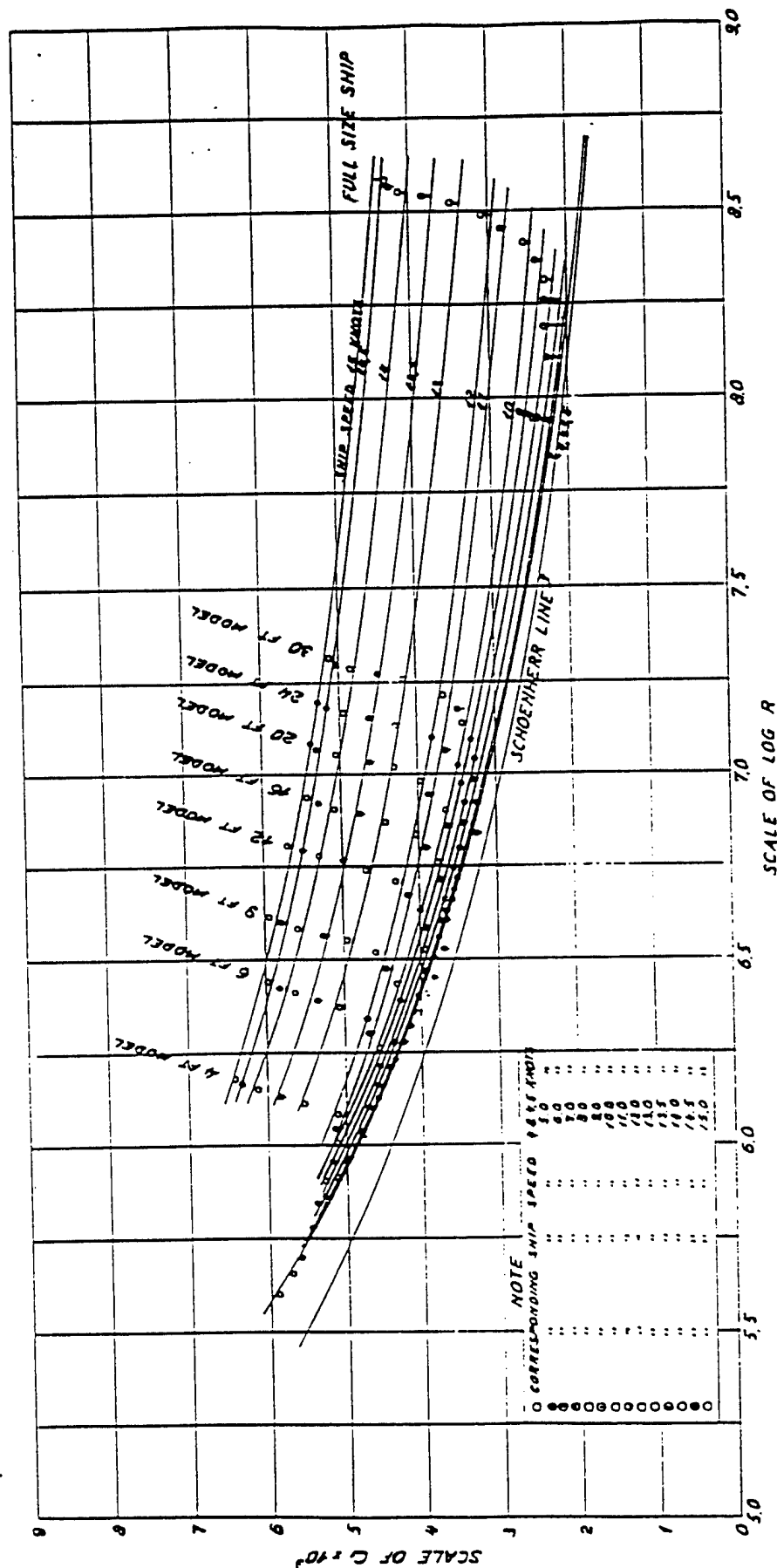


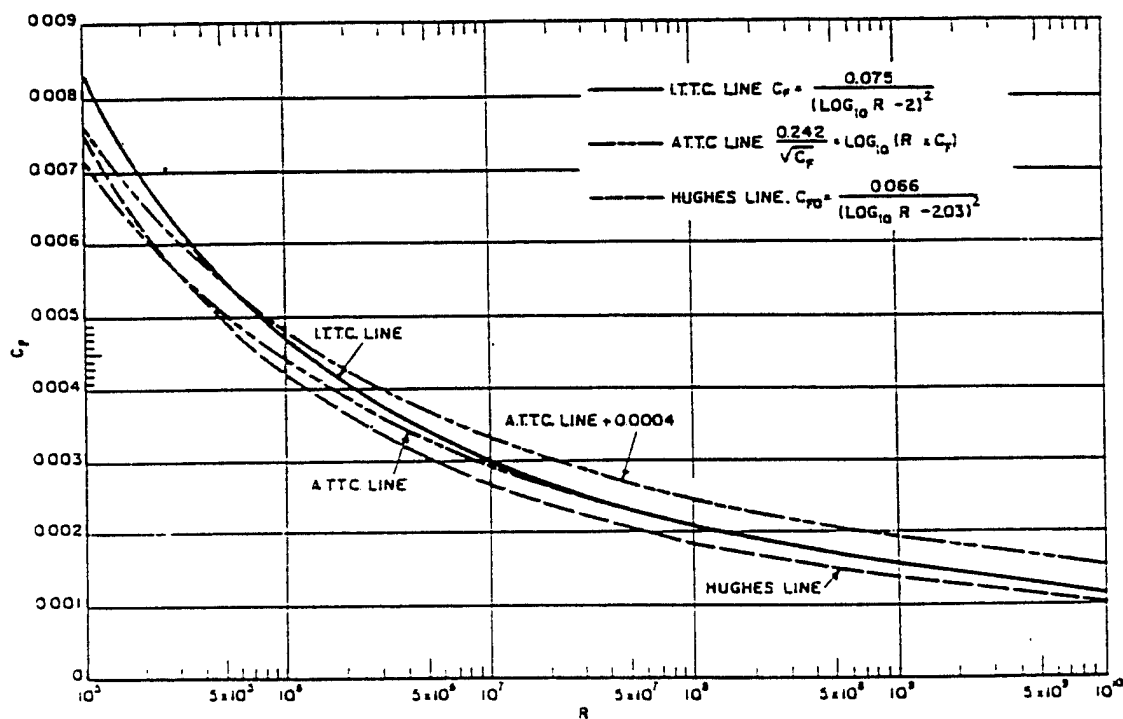
Fig. 1.5. Drag coefficient for spheres as a function of the Reynolds number

Curve (1): Stokes' theory, eqn. (0.10); curve (2): Oseen's theory, eqn. (0.13)



## 2.11

Total drag coefficients of the *Lucy Ashton* and several geosim models of the same vessel (from Troost and Zakay 1951). The faired curves represent constant values of the Froude number and, if Froude's hypothesis were strictly valid, these would be parallel with spacing independent of the Reynolds number. Note that, even for this small full-scale vessel (58 m long), there is a large gap between the largest model results and the full-scale results.



## 2.12

Frictional drag coefficients or *extrapolators*. The ATTC and ITTC lines are those recommended by the American and International Towing Tank Conferences; the former is identical to the Schoenherr line. (From Todd 1967;

Newman (1977)

Body shape		Reynolds number $R_n$	Dimension ratio $L/D$	Drag coefficient $C_D$
Description	Sketch			
Circular flat-plate normal to stream		$> 10^3$	...	1.12
Rectangular plate normal to stream		$> 10^3$	$\frac{b}{h} = 1, 5, 10, \infty$	1.16 1.20 1.50 1.90
Circular cylinder - axis parallel to stream		$> 10^3$	$\frac{L}{D} = 0, 1, 2, 4, 7$	1.12 0.91 0.85 0.87 0.99
Circular cylinder - axis perpendicular to stream		$10^3$	$\frac{L}{D} = 1, 2, 5, 10, 20, 40, \infty$	0.63 0.68 0.74 0.82 0.90 0.98 1.20
		$> 5 \times 10^3$	$\frac{L}{D} = 5, \infty$	0.35 0.34

Body shape		Reynolds number $R_n$	Dimension ratio $L/D$	Drag coefficient $C_D$
Description	Sketch			
Sphere of diameter D		$10^3$ $3 \times 10^3$	...	0.50 0.20
Hemisphere concave to stream		$> 10^3$	...	1.33
Hemisphere convex to stream		$> 10^3$	...	0.34
Ellipsoid major axis perpendicular to flow		$< 5 \times 10^3$ $> 5 \times 10^3$	$\frac{L}{D} = 0.75$	0.60 0.21
Ellipsoid major axis parallel to flow		$> 2 \times 10^3$	$\frac{L}{D} = 1.8$	0.07
Model airship hull		$> 2 \times 10^3$	...	0.05
Solid cone		...	...	0.34
Solid cone		...	...	0.51

Lampietti & Snyder (1965)

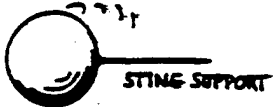

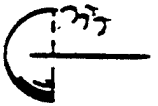
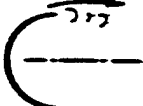


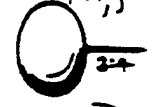

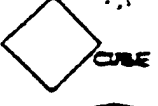

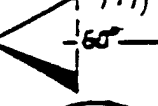

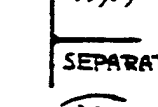
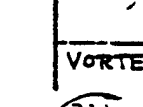
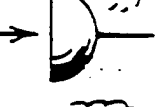

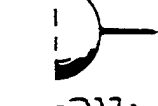
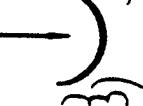




SHAPE	REF.	$C_D$	SHAPE	REF.	$C_D$
		0.47 <sub>+</sub>		—	1.17 <sub>+</sub>
	(c)	0.38		(a)	1.20
	(c)	0.42		(g)	1.16
	(e)	0.59 <sub>+</sub>		(d)	1.60 <sub>+</sub>
	(f)	0.80 <sub>+</sub>		(e)	1.55
	(d)	0.50		(a)	1.55
		1.17			1.98
	(c)	1.17		(a)	2.00
	(b)	1.42		(a)	2.30
	(a)	1.38		(b)	2.20
	(f)	1.05 <sub>+</sub>		(a)	2.05 <sub>+</sub>

Figure 33 (right). Drag coefficients (41) of 2-dimensional shapes (between walls) at  $R$  between  $10^4$  and  $10^6$ . Note: (+) in subcritical flow.

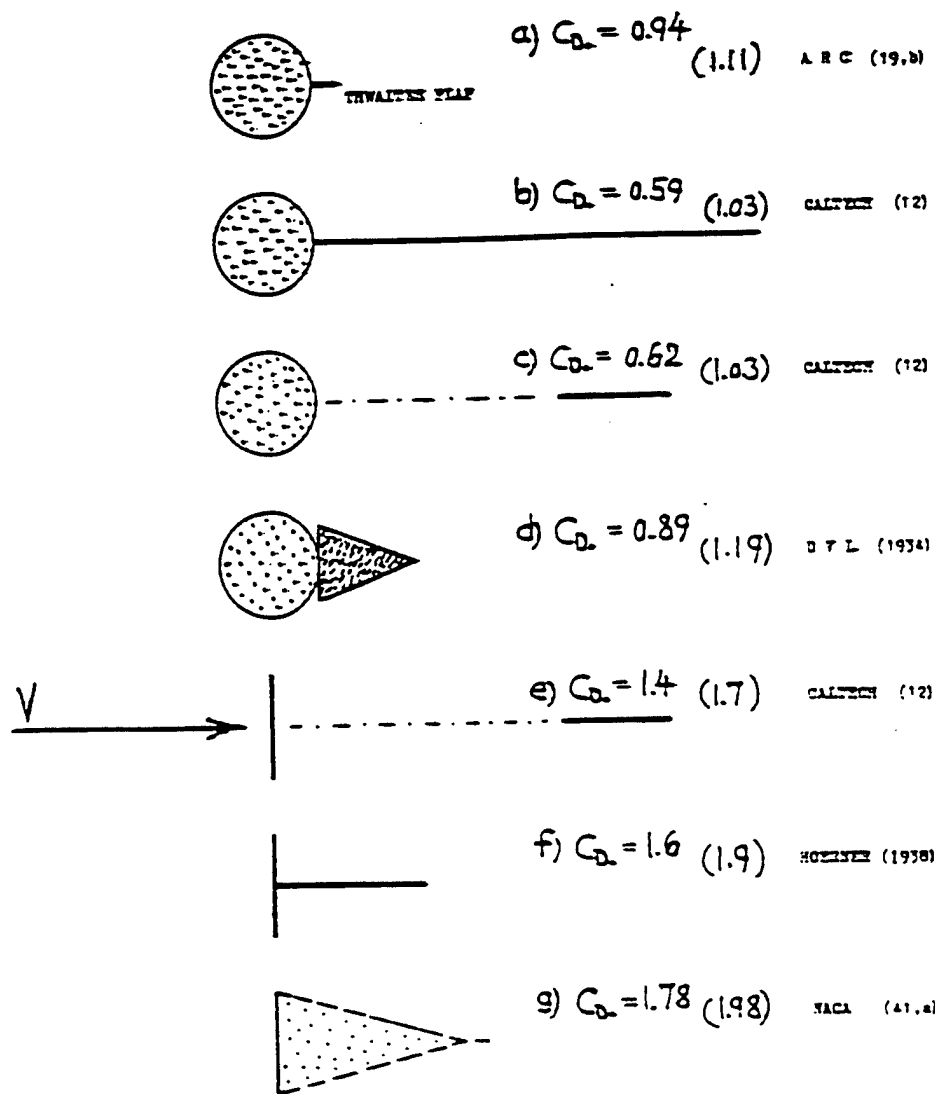
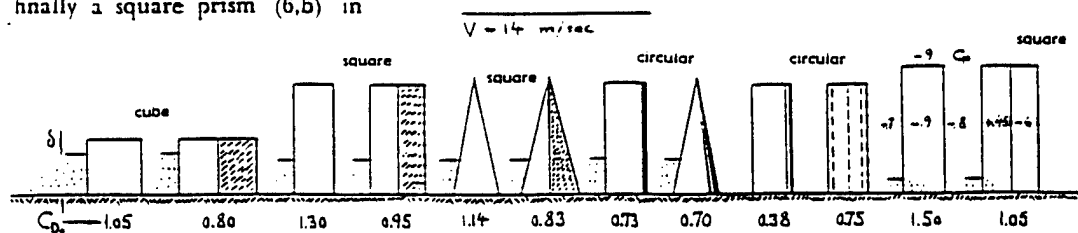


Figure 8. Influence of "splitter" plates (and similar devices) on the drag coefficient of vortex-street-producing shapes (tested between walls). The values in brackets are the drag coefficients without wake interference. The Reynolds numbers (on d or h) are between  $10^4$  and  $10^5$ .

Figure 7. Drag coefficients of simple shapes on ground surface. First 8 bodies from (3.a); then comes a cylinder (8.b) at  $Re = 10^6$ , smooth as well as with 8 ribs on outside; finally a square prism (6.b) in two positions.



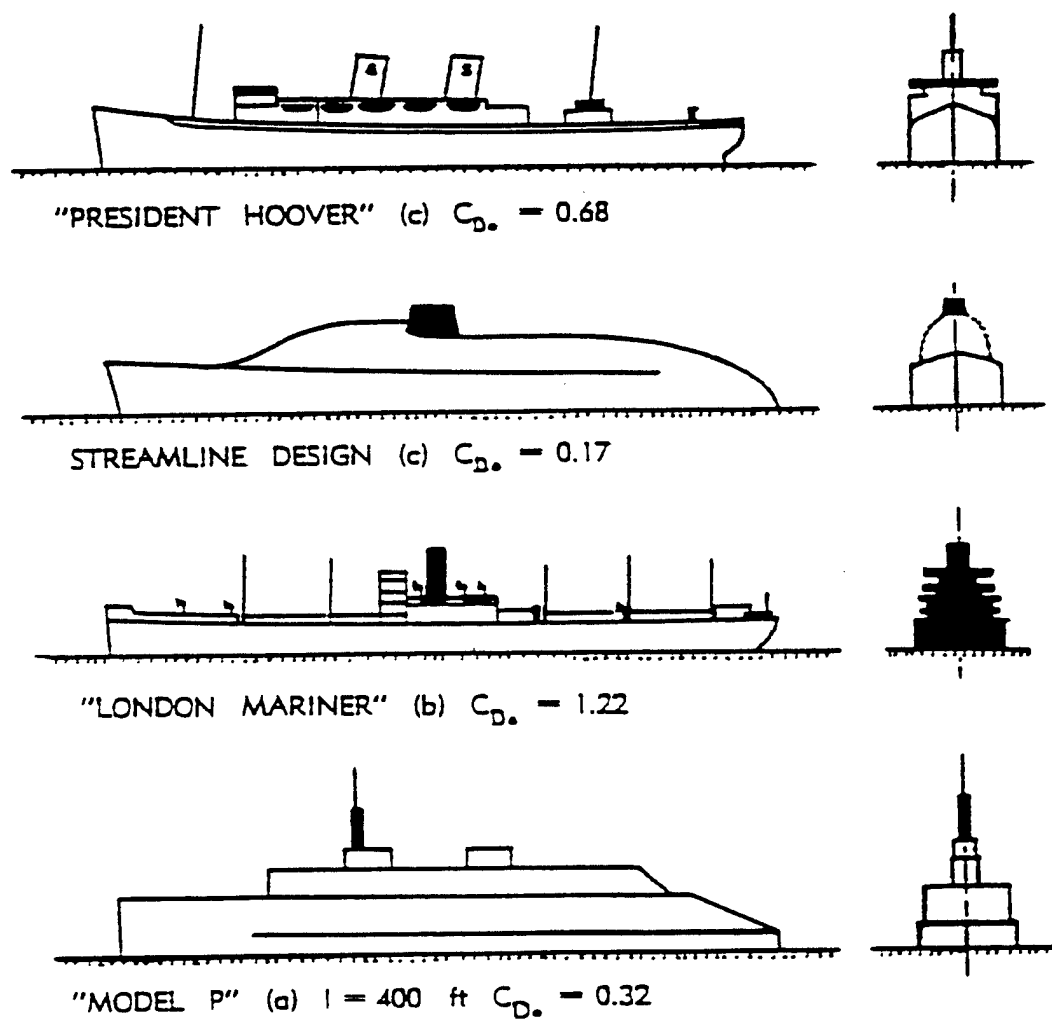


Figure 7. Aerodynamic or wind resistance of several ship models (6). The coefficient  $C_{D_s}$  is based on projected frontal area of hull (above waterline) plus superstructure.

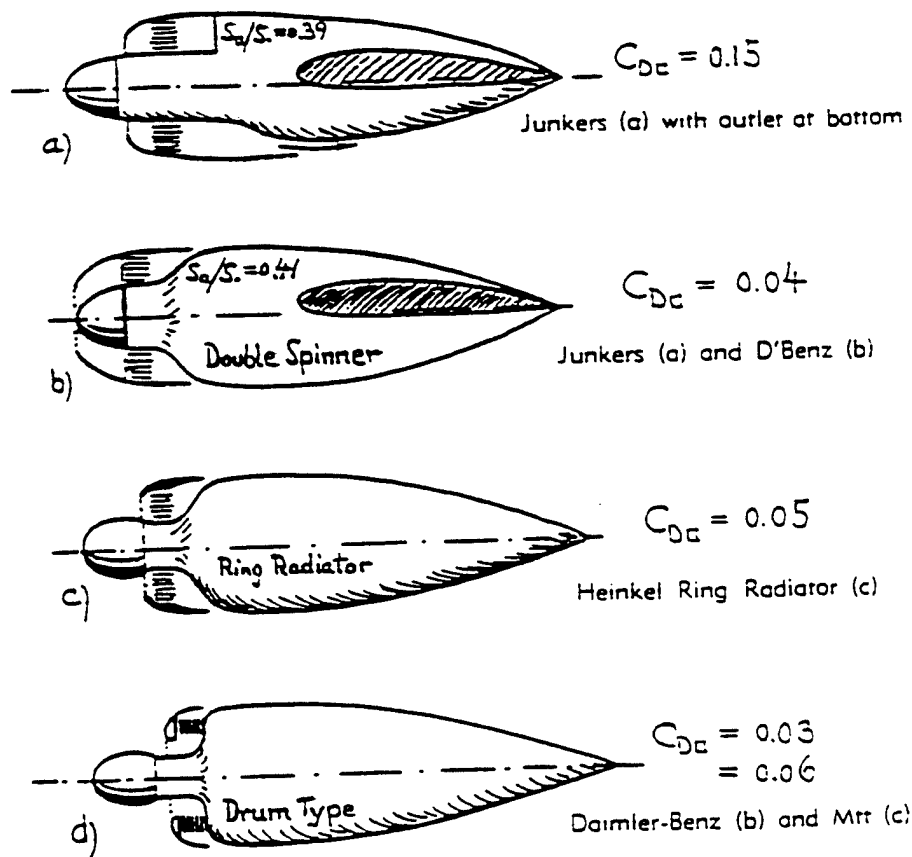
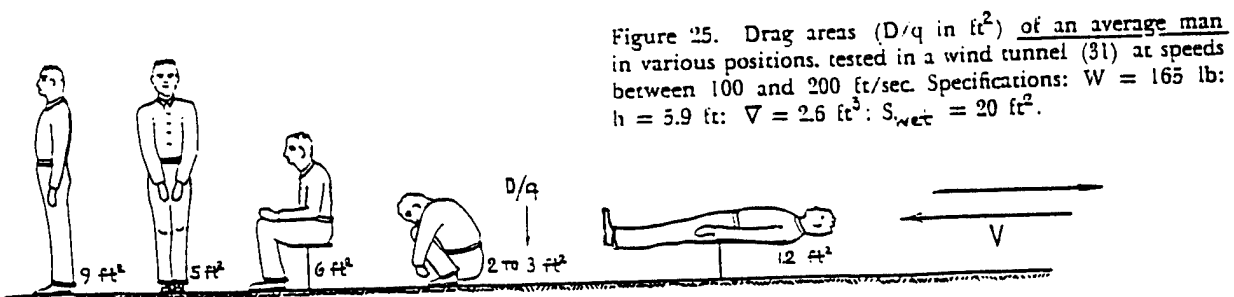


Figure 8. Shape and drag of ring-type radiators (5).



Hoerner (1965)